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Surface quality of furniture components using a band saw, milling machine, and two species

Qualidade superficial de componentes de móveis utilizando serra fita e fresadora e duas espécies

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ABSTRACT

This study is dedicated to considering the use of eucalyptus and *Ocotea porosa* to produce classic-style furniture, assessing the machining time and surface quality. For such, the survey of data on the surface quality of eucalyptus and *Ocotea porosa* pieces was carried out through a visual assessment with the adaptation of the methodology described in standard ASTM 1666. This analysis of the wood surface quality occurred using two different species and two machining modalities (a band saw and a copy milling machine) for parts intended to produce components (feet) for classic furniture. After making the feet, the pieces of furniture were assembled and reassessed. Forty samples were selected and evaluated for initial defects through visual inspection, and the non-parametric Kruskal-Wallis statistical test was applied. The values found for surface quality were considered good quality, with more time being necessary to perform the finishing of the parts processed with the band saw than the milling machine. One may conclude that the milling time spent on each treatment influences the production capacity of the company, with the cuts carried out with the milling machine being faster and with better surface finishing.

KEYWORDS: machining, non-parametric analysis, surface finish.

RESUMO

Esse estudo dedicou-se a considerar a utilização de eucalipto e *Ocotea porosa* na produção de móveis em estilo clássico, avaliando o tempo de usinagem e a qualidade superficial. Para tal, foi realizado o levantamento de dados sobre a qualidade superficial de peças de eucalipto e *Ocotea porosa*, por meio de uma avaliação visual com adaptação da metodologia descrita na norma ASTM 1666. Essa análise da qualidade superficial da madeira ocorreu por meio de duas diferentes espécies e conduzido por duas modalidades de usinagem (uma serra-fita e uma fresadora copiadora) de peças destinadas a produção de componentes (pés) para móveis clássicos. Após a confecção dos pés os móveis foram montados e novamente avaliados. Selecionou-se 40 amostras, nas quais foram avaliados os defeitos iniciais por meio da inspeção visual, foi aplicada a estatística não paramétrica de Kruskal-Wallis. Os valores encontrados sobre a qualidade de superfície foram considerados de boa qualidade, sendo necessário maior tempo para realizar o acabamento nas peças processadas na serra-fita se comparado com a fresadora. Pôde-se concluir que o tempo de usinagem gasto em cada tratamento influencia na capacidade de produção da empresa, sendo mais rápidos os cortes realizados pela fresadora com melhor acabamento superficial.

PALAVRAS-CHAVE: usinagem, não paramétrica, acabamento superficial.

INTRODUCTION

Among planted species, eucalyptus presents several advantages regarding the applicability of the wood relative to other species, such as the rapid growth, raw material cost, homogeneity, and climate adaptability. Even though eucalyptus wood may be utilized as raw material for battens, cellulose, and energy production, it is not traditionally used in furniture manufacturing (SOUZA et al. 2009). Wood apparent density, cleavage, deformations, and machinability are the most important parameters for wood processing (DAVIS 1962).

According to GALINARI et al. (2013), eucalyptus wood comes from short-cycle plantations, which raises a certain preference for native species in consumers and producers. This is considered the major drawback for the expansion of the use of eucalyptus in furniture. However, this wood is also destined for the coal and cellulose industries, which require different technological characteristics compared to solid wood.

According to LOPES et al. (2014), the potential of eucalyptus in the manufacturing of solid products has been explored in recent decades.

The trees of *Ocotea porosa* (*Ocotea porosa*), which belongs to the *Lauraceae* family, may reach heights of 10 m to 20 m and diameters of 50 cm to 150 cm. The basic properties of the wood are a specific mass of 0.54 $g.cm^{-3}$ and an apparent density of 0.65 $g.cm^{-3}$ (MAINIERI & CHIMELO 1989). According to CARVALHO (2003), this species has always been fundamental to worldwide economic and cultural development, while MELO JÚNIOR (2017) stated that *Ocotea porosa* was heavily exploited for structural and export purposes until the mid-20th century. INOUE et al. (1984) considered *Ocotea porosa* to be wood with good performance in processing as well as in finishing due to its technological properties and versatility. LORENZI (1992) stated that its wood is moderately heavy (0.65 $g.cm^{-3}$), hard, glossy, smooth, resistant, with an irregular surface and great durability even when exposed to the elements. FERREIRA et al. (2015) added that *Ocotea porosa* exhibits good workability, besides being easy to turn.

According to SOUZA et al. (2009), the furniture industry in Brazil became relevant in the 1940s. The furniture production chain encompasses several processes involving different raw materials, resulting in a diversity of final products. It may be segmented according to the materials the pieces of furniture are made of or according to their final use (i.e., furniture for residence or office use; made of solid wood or medium-density fiberboard - MDF).

The furniture segment may be classified into rectilinear, turned, and tailor-made. Among turned furniture, classifications are made according to the raw materials used: hardwood, which exhibits a high degree of technological heterogeneity, and reforestation woods, preferred by most serial turned furniture manufacturers, who export a great part of their production (GALINARI et al. 2013).

Classic-style furniture designs tend to present a high complexity of execution, so it is important to improve the manufacturing process by applying techniques that reduce the dependence on specialized labor. Native species such as *Ocotea porosa* show excellent results in terms of finished product quality; however, they have become expensive and little available in the market. An alternative to this problem is viability studies on applying other wood species that are supplied in greater quantity yet result in parts with similar technological characteristics.

Carpentry practices require specific knowledge, in addition to being essentially handmade work. As the process is discontinuous, its automation is complex, and the standardization of the items produced is poor (GALINARI et al. 2013). It is important to verify the variation of these properties through macro and microscopic measurements. Machinability may be described as the relationship that the wood presents with the cutting tool (CSANÁDY & MAGOSS 2012). Concerning machining operations, NOVÁK et al. (2011) defined milling as a technological operation aimed at modeling the surface and dimensions of wood pieces, which contemplates the wood workability. According to LATORRACA & ALBUQUERQUE (2000), the term machining refers to the degree of ease of processing wood through the use of instruments, having as its objective not only to unfold it but to produce a desired shape relative to the dimensions and surface quality as accurately and economically as possible. The superficial nature of solid wood is a function of machining quality, which is directly related to knife marks per centimeter and not just the speed of the cutting head.

In the United States (US), one of the most important criteria for workability is surface smoothness, and one method used to analyze this is visual inspection with grades 1 through 5 (DAVIS 1962). Surfaces of simple, flat, and also complex shapes are obtained when the wood surface is machined (SALCA 2015). Sawn surfaces with properly adjusted straight band saw blades are suitable for both structural and non-structural joints (ÖZÇIFÇI & YAPICI 2008).

Milling machines are machines used for machining that may be semi or fully automatic and, according to their working conditions and cutting principles, by using these machines, cutting processes such as grooves, beads, and chamfers may be performed easily (GOK et al. 2014).

This study aimed at comparing the performance of *Ocotea porosa* and *Eucalyptus grandis*, as well as the use of a band saw and a milling machine in the production of classic-style furniture prototypes in terms of operating time and surface quality. The surface quality was assessed before and after the machining operation.

MATERIAL AND METHODS

This study was conducted from June to December 2013 at the company Mikuska Móveis, located in the municipality of Pinhais, Brazil (latitude 25°25'57" S, longitude 49°11'35" W, altitude 995 m).

The *Ocotea porosa* and *Eucalyptus grandis* wood used in this study originated in the municipalities of Castro and Telemaco Borba (Brazil), respectively. The average densities found were 0.67 $g.cm^{-3}$ or *Ocotea* *porosa* and 0.50 g.cm^{-3} for eucalyptus.

The wood was sawn and cut into blocks, which were unfolded only secondarily, making them ready for processing. Before being machined, the parts were marked according to a cutting plane in order to minimize waste. The specimens were converted from their raw state into pieces of dimensions 6.5 cm x 6.5 cm x 28.0 cm.

The samples were divided into four experimental groups consisting of ten specimens each. Specifically, ten pieces of *Ocotea porosa* were machined with a band saw and ten others with the milling machine. The same procedure was repeated with *Eucalyptus grandis*. Within each group, the pieces were marked with radial, tangential, and mixed-orientation cuts to test whether the cutting orientation interfered with the final finish of the machined parts.

The band saw specifications was by brand Rockwell Invicta, model 1814, and had a tape length 4.60 m, a three-phase induction motor by brand Kohlbach, model 56H 18/99 40342210.000 11E-2206, Hz 60, rpm 1720, V. 220/380, 4x, FS 1,15, A 6,3/3,6; Ip/In 6,5/ cat N; AFS. The copy milling machine saw specifications was by brand Dalmaq, model FC 1150 - 2013 series category C3, with Speed 7000 rpm, maximum cutter height 120 mm, diameter 80 mm to 100 mm, hand feed, maximum milling length 1150, maximum workpiece height 180 mm, 3-HP 2-pole, 6 bar motor (Figure 1).

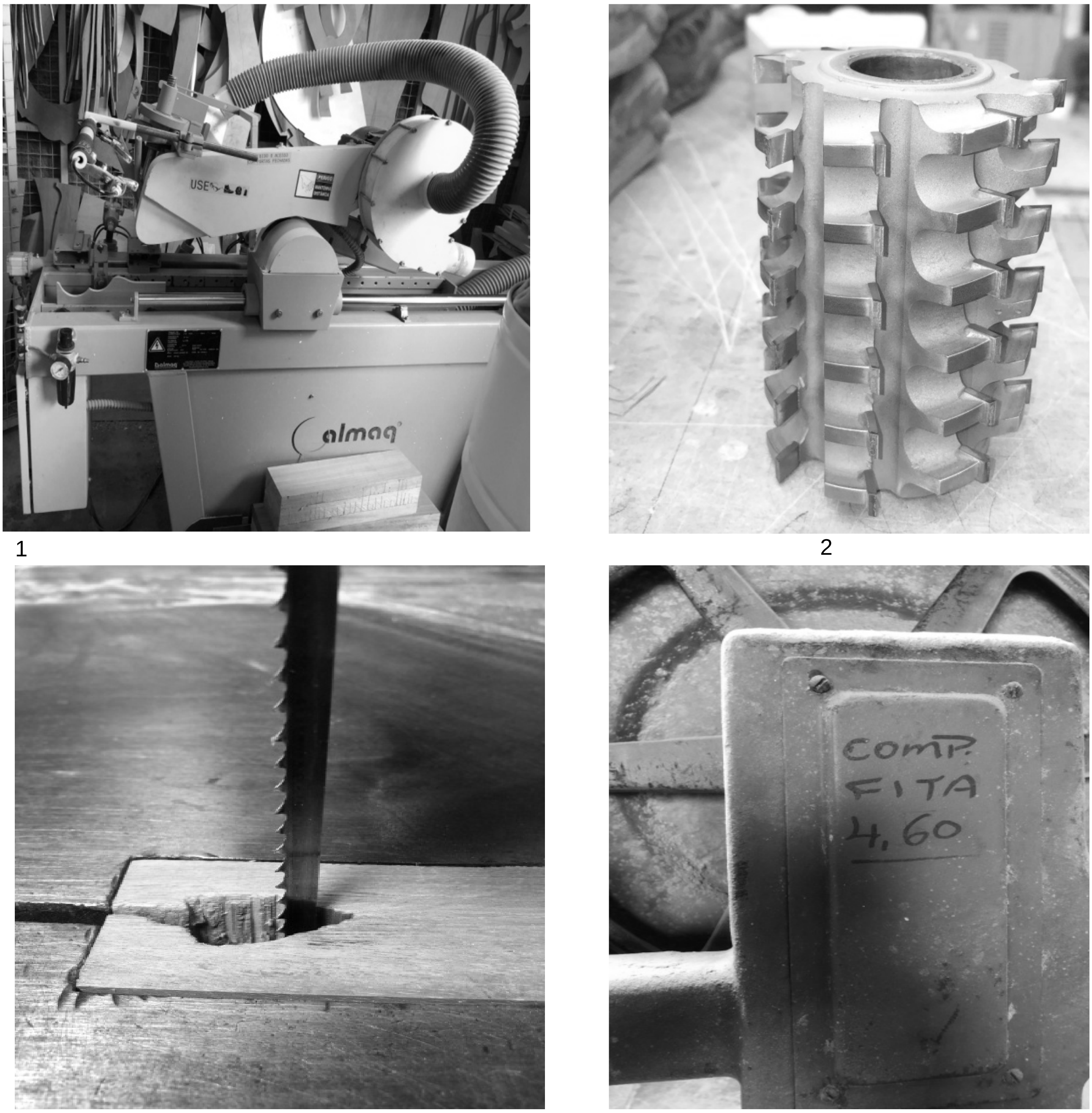

Figure 1. Details of the band saw (3, 4) and milling machine (1, 2).

The finishes yielded by both wood species were evaluated before and after machining. Scores ranging from 1 to 5 were assigned to each sample in relation to surface quality according to the method adapted and described in ASTM D 1666 - 17 Standard Test Methods for Conducting Machining Tests of Wood and Wood-Base Panel Materials, where 1 represents the best performance and 5 the worst. The evaluation was performed based on the questionnaire shown in Table 1. Two experimental designs were built from this questionnaire, one according to the wood species and the other according to the presence or absence of finish.

Table 1. Questionnaire on surface quality.

Evaluation of prototypes	
Furniture	Score
Eucalyptus grandis with finish	
Ocotea porosa with finish	
Eucalyptus grandis without finish	
Ocotea porosa without finish	

The tests were evaluated by eight technically qualified professionals according to the method described in ASTM D 1666 (2015), thoroughly analyzing the details of each part in order to detect machining defects that could compromise their final quality. The cutting orientation of each part was identified so that the final quality could be evaluated in terms of radial, tangential, or mixed cutting orientation. The reliability of the scores attributed to the parts was based on the knowledge of the evaluators.

In this study, no roughness or surface analysis tests were used. The exam took place using the finished pieces and was carried out by a group of woodworkers with three to ten years of experience. The main focus of the analysis was the non-parametric perception of the professionals and their considerations on two machining methods. The use of a rugosimeter would only indicate that the *Ocotea porosa* species has less roughness than *Eucalyptus grandis* but would not show the perception of woodworkers using wood.

The control samples were subjected to machining operations using the band saw and the milling machine according to an adaptation of ASTM D 1666 (2015), following the procedure described in the standard method. For each sample, the result was classified into five categories (Table 2).

Table 2. Classification of wood machining quality according to ASTM D 1666 (2015).

Classification	Score
Excellent – free of defects	1
Good – low incidence of defects	2
Regular – slightly defective	3
Bad – frequent occurrence of defects	4
Poor – high indicence of defects	5

The wood parts were initially assessed for superficial irregularities. Following cutting in standardized sizes, each piece was analyzed separately. All the samples were submitted to the analysis of superficial quality following the same procedure.

The operating time determinations were collected with a simple chronometer, which was activated at the start of machining for both machines.

The statistical analysis was initially performed employing the Kolmogorov-Smirnov and Shapiro-Wilk tests; however, since no normality was found, the non-parametric Kruskal-Wallis analysis was applied based on the H-statistic. All tests were performed using the statistical package Statgraphics Centurion XVI at a 95% confidence level.

The surface quality scores were analyzed using the non-parametric Kruskal-Wallis test, while the machining time results were assessed using Tukey's test with a significance level of 0.05. The Kruskal-Wallis test is a non-parametric test used to compare three or more independent samples and indicates whether there is a difference between at least two of them. The test transforms numeric values into categories, which are grouped into a single data set. The groups are then compared by the average of these categories. The Kruskal-Wallis test was used to compare two paired samples in terms of wood species and finish quality, with an efficiency of 95%.

RESULTS

The processing time results given by each piece of equipment are presented in Table 3. The average time required to cut the pieces from the initial block was longer when the band saw was used: 111 s for *Ocotea porosa* and 99 s for *Eucalyptus grandis*. In comparison, the milling machine yielded average times of 83 s for *Ocotea porosa* and 85 s for *Eucalyptus grandis*, and the cutting operation was easier.

The Kruskal-Wallis test applied to the surface quality scores did not show significant differences between the groups sampled before the machining procedure (X^2 = 0.74 < p-value = 0.864), as shown in Table 3.

Table 3. Comparison of machining times for each equipment and wood combination.

Combination	Average machining time (s)
Ocotea porosa – Milling machine	82.60^{a}
Eucalyptus grandis – Milling machine	85.00^{a}
Eucalyptus grandis – Saw band	99.50^{ab}
Ocotea porosa – Saw band	111.60^{b}
p-value	0,000
F value	8,967

Although the results shown in Table 4 are numerically different, the test did not reveal statistically significant differences between groups. This means that all the wood parts had the same level of quality regardless of their species or cutting orientation. Although *Ocotea porosa* presented the highest absolute result, the differences between woods are not statistically significant; therefore, *Eucalyptus grandis* is an alternative for the carpentry and furniture industries. *Eucalyptus grandis* may also be applied in the internal structure of upholstery. Note that the lower the score is, the better the surface quality.

Table 4. Surface quality scores assigned to wood species processed with different pieces of equipment.

Comparison group by species	Species group description	Score
Ocotea porosa	Saw band	2.25 ± 1.21
	Milling machine	1.74 ± 0.73
Eucalyptus grandis	Saw band	2.04 ± 1.03
	Milling machine	1.87 ± 0.91

Legend: the lower the score, the better the surface quality.

As the Kruskal-Wallis test did not compare the means directly, pairwise comparisons of the treatments were made to compare the wood species and the pieces of equipment, with results shown in Table 5.

Table 5. Surface quality of the machined parts and the associated Kruskal-Wallis classification.

Comparison group by machine	Machine group description	Score	Average ranking
Saw band	*Ocotea porosa*	2.5 ± 1.20	11.65
	Eucalyptus grandis	2.26 ± 1.11	9.35
Milling machine	*Ocotea porosa*	2.16 ± 1.15	10.10
	Eucalyptus grandis	2.25 ± 1.08	10.90

The Kruskal-Wallis test showed differences between the wood species machined with the band saw. In addition, *Eucalyptus grandis* presented a superior surface quality than *Ocotea porosa*, attributed to the care of the operator while cutting (precision and training) and the adjustment of the machine.

Regarding the tests performed with the milling machine, the two wood species had the same statistical results. However, *Ocotea porosa* exhibited slightly better surface quality than *Eucalyptus grandis*.

The surface quality results focusing on differences between wood species are presented in Table 6.

Eucalyptus grandis showed the same behavior with both pieces of equipment. However, the milling machine reached the quality goal sooner than the band saw. There are no studies in the literature to allow a comparison. In contrast, *Ocotea porosa* showed statistically significant differences according to the machinery used. The milling machine provided better surface quality than the band saw in terms of cut precision and shorter time required for the cutting operation.

Table 6. Surface quality of the machined parts and the associated Kruskal-Wallis classification.

Group description group by species	Score	Average Ranking
Eucalyptus grandis – Saw band	2.26 ± 1.11	11.10
Eucalyptus grandis – Milling machine	2.25 ± 1.08	9.90
Ocotea porosa – Milling machine	2.16 ± 1.15	122.00
Ocotea porosa – Saw band	2.50 ± 1.20	88.00

The milling machine is better recommended than the band saw due to its better surface quality and significantly shorter execution time. Additionally, the operations performed with the band saw resulted in a higher incidence of irregularities and defects.

In general, *Eucalyptus grandis* has greater availability and provides surface quality compatible with that of *Ocotea porosa*, in addition to outperforming *Ocotea porosa* in terms of cut precision when a band saw is used. Furthermore, this is a promising species for the furniture industry as it presents desired characteristics in relation to aesthetics, easy machinability, and excellent surface quality.

A comparison of surface quality before and after machining is showed in Table 7.

Table 7. Statistical comparison by the Kruskal-Wallis test in relation to the use of finishing.

Comparison of unfinished furniture		
U value	-0,6860	
p-value	0,2463	
Comparison of finished furniture		
U value	4.230	
p-value	0,0001	
Finishing effect	*Eucalyptus grandis*	*Ocotea porosa*
U value	-0,0857	3.976
p-value	0,5300	0,00003

Concerning the furniture produced without the finishing step, the p-value above 5% indicated that the finished surfaces did not present statistically significant differences. Even though Figure 2 shows that the unfinished furniture made with *Ocotea porosa* wood exhibited superior surface quality than the *Eucalyptus grandis* (score 1 represents the best performance, according to ASTM 1666), this difference is not statistically significant.

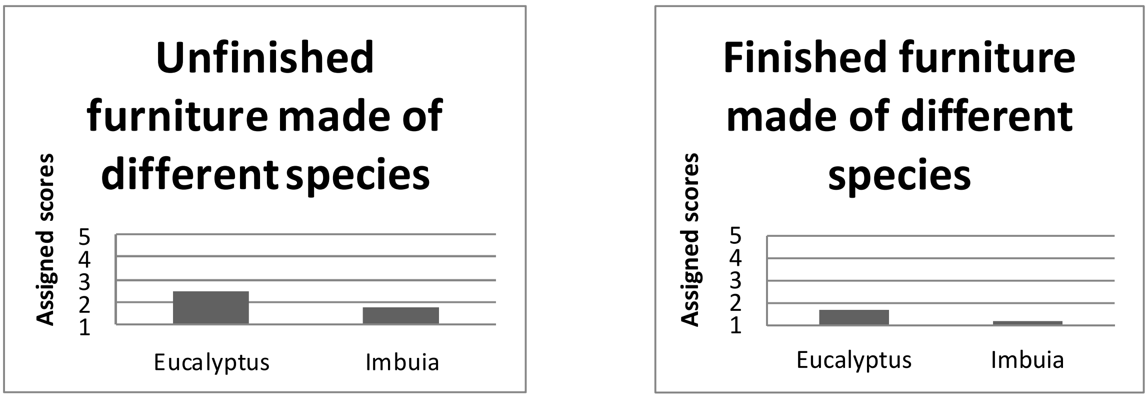

Figure 2. Comparison of furniture made from different wood species with and without finishing.

On the other hand, the furniture with finishing presented statistically significant differences between the wood species. This is emphasized in Figure 1, which shows that furniture made from *Ocotea porosa* had superior surface quality than the pieces made from *Eucalyptus grandis*.

DISCUSSION

A shorter machining time was expected when using the milling machine since this equipment is easier to operate, requires less control by the operator, and the cutting element has a greater speed. When using the band saw, the operator should double the care while cutting, especially in relation to curvatures (i.e., feet). As expected, more curved parts present greater machining complexity.

In the study by CARVALHO (2003), *Ocotea porosa* showed slightly higher surface quality than *Eucalyptus grandis* in band saw processing in relation to machinability and finish quality. INOUE et al. (1984) reported that *Ocotea porosa* is indeed a wood of high workability but did not mention with what equipment the experiments were carried out.

From the finishing point of view, the area that a defect occupies is less relevant than its depth. Therefore, surface quality is influenced by the frequency of occurrence of defects and the severity of such defects. The critical defects of a sample impact the finish quality of a final product since they determine the additional work required to meet the minimum finishing standards.

From the viewpoint of the observer's perception, the size occupied by a blemished area is more important than the depth that a blemish presents. Therefore, the perception of surface quality is related to the number of defects or blemishes. The result of the quality analysis will consist of the frequency of defects in an area relative to the total area of the part, which will impact the final quality required and the additional work needed to reach the previously established standards.

According to SILVA et al. (2015), the quality of *Eucalyptus grandis* wood used to produce furniture must contemplate the plant age variation since older trees yield more sawn wood, dimensional stability, heartwood percentage, higher added value products, and machining quality. The same authors studied the flattening, milling, drilling, and cutting operations using *Eucalyptus grandis* wood. In flattening and milling operations, SILVA et al. (2015) obtained the best results with 25-year-old *Eucalyptus grandis* in both transverse and parallel fiber cutting; however, the 20-year-old species also provided excellent surface quality. PORANKIEWICZ & GOLI (2014) verified that the grain orientation and wood defects exert great influence on wood workability, in addition to the wood species and density. In contrast, BELLEVILLE et al. (2016) observed that grain orientation did not affect the machining of eucalyptus but machining operations that favor grain orientation produced higher quality surfaces. Among the species of eucalyptus studied by them, *Eucalyptus camaldurensis* gave the highest occurrence of chippings after machining.

According to LOPES et al. (2014), species that present interlocked grains result in poorer workability and yield more chippings, as in the case of *Eucalyptus dunnii*, while species with greater density (e.g., *Eucalyptus urophylla*) result in superior quality machining. This is ascribed to the lower percentage of parenchyma and thicker walls. This behavior was observed with *Ocotea porosa* in the present study. The machining of *Eucalyptus benthamii* comprising flattening resulted in sparse fibers, grooves, and open vessel cells in the study by MARTINS et al*.* (2011), while the use of sandpaper yielded a more uniform result.

CONCLUSION

Ocotea porosa presented better machinability than *Eucalyptus grandis*. All professionals who participated in this study were unanimous in indicating this superiority.

Eucalyptus grandis is a feasible alternative to *Ocotea porosa* in furniture manufacturing, even though the surface finishing requires greater care.

The milling machine requires a shorter machining time than the band saw because the use of the milling machine reduces the cut time of the parts since all parts will be machined taking the same time once assisted by the operator.

When machining with a band saw, the cutting operation depends on the operator's experience performing the task. More experienced joiners perform the task with greater precision if they are able to make minor adjustments when they deem necessary. The machining execution time depends on human capacity and the individual perception of the task.

The use of the milling machine reduces the need for prior experience in making curved cuts and advancing the part against the cutting blade, as the machine is autonomously responsible for advancing the part and following the curved cut determined by a wooden jig.

The execution time of the parts is always the same, and the shape of the part curves is predetermined and cannot be changed by the operator. Thus, the milling machine is less subject to individual operator decisions, and cuts can be performed even by an inexperienced operator.

The advantage of using the milling machine is more evident in the comparison because it reduces the effects of human influence.

REFERENCES

ASTM. 2015. Standard Test Methods for Conducting Machining. D1666 -17. Tests of Wood and Wood-Base Panel Materials, West Conshohocken: ASTM International.

BELLEVILLE B et al. 2016. Wood machining properties of Australian plantation-grown Eucalypts. Maderas. Ciencia y tecnología 18: 677-688.

CARVALHO PER. 2003. Espécies arbóreas brasileiras. Colombo: Embrapa. 1040p.

CSANÁDY E & MAGOSS E. 2013. Mechanics of wood machining. Berlin: Springer.

DAVIS EM. 1962. Machining and related characteristics of United States hardwoods. Washington: USDA. p. 68-70. (Technical Bulletin, 1267).

FERREIRA RB et al. 2015. Flautas Transversais Renascentistas: história, construção e experimento com madeiras brasileiras. PER MUSI 31: 108-122.

GALINARI R et al. 2013. A competitividade da indústria de móveis do Brasil: situação atual e perspectivas. Rio de Janeiro: BNDES Setorial 37: 227-272.

GOK K et al. 2014. Failure analysis of support during profile cutting process using horizontal milling machine. The International Journal of Advanced Manufacturing Technology 70: 1169-1179.

INOUE MT et al. 1984. Projeto Madeira do Paraná. Curitiba: FUPEF. 260p.

KININMONTH JA & WHITEHOUSE LJ. 1991. Properties and use of New Zealand radiata pine: wood properties. New Zealand: Forest Research Institute.

LOPES CSD et al. 2014. Avaliação da rugosidade superficial da madeira de *Eucalyptus* sp. submetida ao fresamento periférico. Cerne 20: 471-476.

LATORRACA JVF & ALBUQUERQUE CEC. 2000. Efeito do rápido crescimento sobre as propriedades da madeira. Floresta e Ambiente 7: 279-291.

LORENZI H. 1992. Árvores brasileiras: manual de identificação e cultivo de plantas arbóreas nativas do Brasil. Nova Odessa: Plantarum. 352p.

MAINIERI C & CHIMELO JP. 1989. Fichas de características das madeiras brasileiras. São Paulo: IPT. 418p.

MARTINS AS et al. 2011. Efeito da usinagem na rugosidade da superfície da madeira de *Eucalyptus benthamii*. Floresta e Ambiente 18: 135-143.

MELO JÚNIOR JCF. 2017. O uso da madeira em uma serraria do século XX em Santa Catarina. Balduinia 59: 19-26.

NOVÁK V et al. 2011. Assessment of wood surface quality obtained during high speed milling by use of non-contact method. Drvna industrija 62: 105-113.

ÖZÇIFÇI A & YAPICI F. 2008. Effects of machining method and grain orientation on the bonding strength of some wood species. Journal of Materials Processing Technology 202: 353-358.

PORANKIEWICZ B & GOLI G. 2014. Cutting forces by oak and douglas fir machining. Maderas. Ciencia y tecnología 16: 199-216.

SALCA E. 2015. Optimization of wood milling schedule–a case study. Dimensions 2000: 160.

SILVA JC et al. 2015. Influence of age on wood machinability of *Eucalyptus grandis* Hill ex. Maiden for use in the furniture industry. Scientia Forestalis 43: 117-125.

SOUZA MOAD et al. 2009. Avaliação da madeira de *Eucalyptus camaldulensis* Dehnh e *Eucalyptus urophylla* ST Blake em ensaios de usinagem, visando à produção moveleira. Árvore 33: 751-758.